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The Conception of Rickyshi the Sumo Robot

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I. Introduction

Sumo is a traditional style of wrestling that originated in Japan in which two competitors fight to push each other out of a ring. The first person to exit the ring or touch the ground with something other than their feet is the loser of the match[6]. The popularity and cultural history of sumo consequently led to the development of robots who face off against each other in robot sumo competitions. These competitions, which started in Japan in 1989 with the aim of getting students involved in robotics [1] and are now held worldwide. While different competitions have varying rules and regulations, there are general guidelines that all entrants must follow, including:

- Robots must not damage each other.
- Entrants must be within certain weight and size requirements.
- The robot may be either autonomous or remotely controlled.

The goal of robot sumo is similar to regular sumo in that the aim is to push the opponent out of the ring. Two robots start on opposite sides of a ring and attempt to gain the upper hand by using different strategies such as brute force, unbalancing the opponent, or attacking from the back or side. This technical report describes the design, construction and performance of a robot named Rickyshi built by the authors, who are students in a Mechatronics course and entrants in a robot sumo competition organized by the professor. The objective is to make a robot which can sense the edge of the ring and stop itself from driving out of the ring. A secondary goal is winning the sumo competition against the sumo robots constructed by other students. The report includes explanations into how the design was chosen in order to comply with the rules of the competition, including size, weight, and cost restrictions. A complete list of rules and requirements for the competition can be found in Appendix A.

II. Design and Fabrication

A. Strategy/Design Overview

Rickyshi is optimized for traction. It employs the strategy of generating more horizontal force than an opponent to push them out of the ring in a head-on collision. Defensively, the high traction makes it hard for an opponent to push Rickyshi out of the ring when approaching from any side. The design achieves this goal through the use of high-torque motors and high-friction wheels. This naturally decreases the speed of the robot as a greater proportion of the motor's power is used to provide torque. The wheels have a casted silicone outer layer with a high friction coefficient against the rubber mat of the arena. Rickyshi has four driven wheels to ensure the robot always has the most normal force possible, and additionally maximize the contact area of the wheels such that the greatest tractive force is achieved. Additionally, the low center of mass of the robot prevents it from getting pushed over. The mass of the robot was chosen to be close to the maximum allowable weight of 5 lbs, at a weight of 4.56 lbs, to maximize the normal force, and consequently maximize the tractional force available to the robot for forward movement. Rickyshi also boasts a very compact design with a body size of 220x162x71mm. Due to its small frontal and side profile area, it is less susceptible to getting spun by an off-center strike than a longer or taller robot. The front wedge of the robot, a thin sheet of steel, touches the ground in order to prevent the wedges of other robots from slipping underneath. Due to Rickyshis small size, the steel wedge could also be very long, allowing it to get deep underneath the opponent. If the wedge gets underneath an opponent robot, the opponents wheels can be lifted off the arena making the opponent's wheels useless. The reflective sheet metal of the wedge also encourages the possibility of triggering the opponents IR sensors, which may cause them to turn around and drive themselves out of the ring. Additionally, the opponent's weight is placed upon Rickyshi which gives it a greater pushing force. The robot is precise due to the implementation of ultrasonic sensors that allow it to determine whether an opponent is in front of it and continue driving forwards even if it senses the edge of the ring. Overall, the robot's unique design features, coupled with its technical capabilities, give it an advantage over its opponents on the arena floor.

B. Mechanical Design

Rickyshi is designed with an internal section that includes the battery pack, printed circuit board (PCB), motors, and wheels. These parts are supported by two layers of acrylic offset using 3D printed standoffs. The internals are protected by an exoskeleton structure which mounts to the uppermost internal acrylic layer. The entire robot, seen fully assembled in Figure II.1, is designed to be mechanically robust to impacts. This is accomplished through the use of ASA[1] , a 3D printing plastic which has high mechanical strength and resistance to weathering. Cast acrylic is used for flat pieces instead of ASA in order to achieve weight savings. All of the pieces are held together with M4 bolts, washers, nuts, and threaded inserts. These were chosen for their strength and to allow for ease of modification.

1) Fabrication: RickyShi is fabricated using rapid-prototyping techniques which provide the benefit of quick speed of production. The techniques used are mainly 3D printing and laser cutting, which are operations that can be done with relatively little hands-on time needed. Specific

[1] ASA, acrylonitrile styrene acrylate, this was included because we wanted to include a footnote

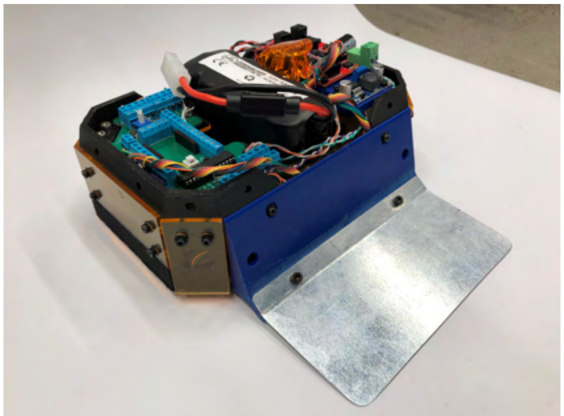

Fig. II.1. Rickyshi's sheet metal wedge barely touches the ground to prevent opponents from getting underneath.

parts require more time-intensive fabrication techniques and are described in detail below.

Fig. II.2. Frame assembly with layers of acrylic and motor mounts surrounding the battery.

The internal section of the robot uses a two-layer frame of laser-cut acrylic sheets, as seen in Figure II.2. In the upper layer, slots are cut for the battery, wires, and fasteners. Four motor mounts symmetrically sandwich the battery in the center of the frame and function as standoffs between the two acrylic layers. The motor mounts are made of 3D-printed ASA. The top half of all four mounts are glued to the upper acrylic plate. The entire frame section is held together with M4 bolts which pass from the top half of the motor mounts through the bottom half and the lowest acrylic plate. The cylindrical motors are held securely in place by the clamping action and friction generated by tightening the bolts into the heat-set inserts into the bottom half of the motor mounts.

The motor shafts interface with the wheels using a mounting

Fig. II.3. A motor hub attached to the motor axle.

hub machined from an aluminum rod, seen in Figure II.3. The process of making the hubs is as follows. The rod is placed into the lathe and a central hole with the diameter of the motor shaft is drilled to the depth of four hubs and the outer diameter of the rod is turned to the diameter of the motor hub flange. The shaft of the motor hub is then turned to the right diameter from the free end of the rod, after which the completed hub is cut at the right length for the flange width and the edges are filed down and the holes are de-burred. This is repeated 3 more times for the 4 motor hubs. Each hub blank is then clamped in the mill, where four concentric holes for M3 bolts are drilled 90 degrees apart. The hub is then clamped sideways and a final set screw hole is drilled radially inwards 45 degrees from the mounting holes. An M3 tap is used the thread the mounting holes and set screw holes. The drawing can be found in figure C.3 in the Appendix. The mounting hub connects to the D-shaft of the motor using an M3 set screw in the set screw hole.

The wheels have four 3mm through holes aligned with the mounting holes and are attached to the motor hub using 4 M3 15mm screws, pictured in figure II.4. The full assembly can be seem more clearly in the exploded CAD in figure C.4 in the appendix. To maximize the contact surface area of the wheels while still minimizing the amount of space they occupy, the wheels overlap the motor by attaching the motor to the inside of the concave side of the wheel. These wheels were made by 3D printing a PLA rim and casting the silicone tire around it using a 3D printed negative mold of the wheel, seen in figure II.5. The wheel rim consists of a cup-shaped body with T-shaped fins extending radially from its walls. The purpose of these fins is to hold the silicone in place, as silicone does not stick well to anything except itself; the silicone flows around the fins as it is cast as seen in figure II.5 and cures to harden around the fins. The silicone used is DragonSkin 20 silicone with a shore A hardness of 20. This silicone was found to have

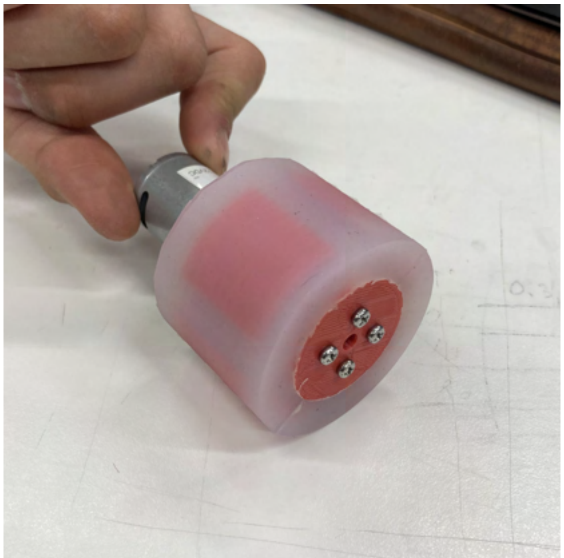

Fig. II.4. PLA rims with molded silicone tires attached via M3 15mm screws.

very good traction against the rubber arena, while also being durable enough to last multiple battles.

Fig. II.5. Casting process of the silicone wheels.

The shield walls are part of the exoskeleton and used as a base to mount the acrylic outer sheets to. They are 3D printed using ASA and attach on the short sides of Rickyshi's internal frame using M4 bolts, as depicted in Figure II.6. In each corner of the shield walls, there are pegs in the shape of the outer edge of an IR sensor which snugly fit the sensor pointing downwards.

The outermost acrylic sheets to attach to a wedge which is shown in Figure II.1. Regarding the wedge, it is designed to be a shallow wedge, reaching down to the ground as a skirt to prevent opponent wedges from getting underneath the robot. The wedge lifts the front wheel up slightly to ensure no other wedge can get under it. When the opponent drives on top of the wedge, it provides extra normal force and engages the front two wheels. The wedge is mounted with M4 bolts screwed into

Fig. II.6. Shield wall being fit into place on the upper frame layer of acrylic.

M4 threaded inserts melted into the wedge, passing through holes in the acrylic outer shield. The lower edge of the wedge has two holes through which M3 bolts are placed to hold a sheet metal piece in place that touches the ground and extends further forward, making it easier to get underneath other robots.

C. Electronics

1) System overview: The robot consists of the following electronic components.

1) Battery
2) Motor Controller
3) Motors
4) IR sensors
5) Threshold Potentiometer
6) Ultrasonic Sensors
7) AVR-ISP Programmer
8) Programming Button
9) Power Switch
10) 12V - 5v Buck converter

Rather than wiring these together on a breadboard and risking loose connections, or using a protoboard and wasting time making connections and debugging, a PCB was made in KiCad and manufactured through JLCPCB. This allowed for minimal human labor, zero time wasted debugging, and made wiring as easy as inserting the wires into the correctly labelled screw terminals. To eliminate human error as much as possible as well as reduce the amount of hand soldering necessary, the decision was made to have all electronic components go directly into the pcb. This is the case even for extremely simple connections such as for the kill switch, which could easily have been soldered in series with the battery line. As shown in figure D.9, a screw terminal was added to wire the switch in series with the battery, all that is required for the assembler is to plug both ends of the switch and both ends of the battery terminals into the appropriately labelled connections. refer to figure II.7 for a preview of the final pcb design.

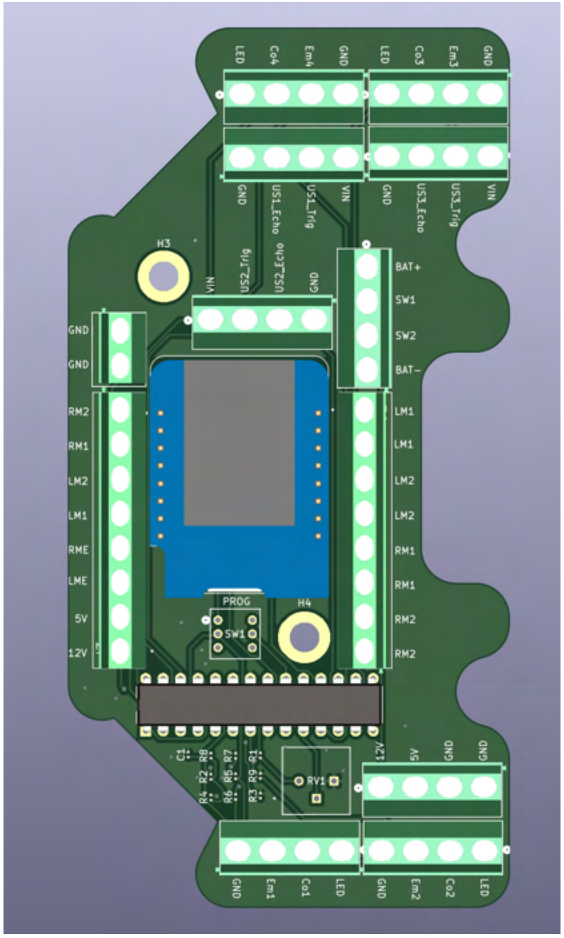

Fig. II.7. A top down render of the pcb

The battery chosen is the Matrix 12V 3000mAh NiMH battery. The battery uses a 20A blade fuse and a Tamiya plug connector, which was wired to the PCB using a Tamiya female plug with open ends to connected to the 12V screw terminals on the PCB. A boost converter module was used to convert the 12V to 5V used for the logic voltage of PCB. The maximum current draw of the entire robot never exceeded 3A which was well within the fuse rating of 20A.

The L298 motor controller which is part of the electronics kit provided by the professor is not used since it needs properly configured latching diodes and gets considerably hot in normal operation. An alternative motor controller is used for the final robot. To remove debugging time, a pre-built motor controller board with pwm capabilities for two motor outputs is used. The new board does not get hot even after long periods of testing. The wiring for the motor controller module is shown in figure D.7.

The motors chosen to drive the wheels are 98 RPM Econ Gear Motors [4]. They are brushed DC motors with a metal gear box. They weigh 91 grams each and take a voltage of 12V. The speed with no load is 98RPM, and the current at no load is 0.1A. The current draw at stall is specified to be 3.8A, but during testing of the motor it was found to be around 2.8A. The torque at stall is 524oz-in. Motors on the same side of the robot (left vs right) were chosen to be wired in parallel. The left side motors were connected to one of the motor outputs on the pre-built motor controller, and the right side motors were connected the other.

Four IR sensors were used for sensing the tape on the edge of the ring. To tune the threshold of these sensors, a potentiometer was wired to one of the analog input pins of the Atmega8. The wiring for the IR Sensors is shown in figure D.5.

The programmer was an esp32 on a Wemos D1 Mini programmed to act as an avr-isp programmer. Any micro controller dev board would have worked, but the Wemos D1 Mini was chosen for its small form factor and low cost. Because the programmer needs to connect to the reset pins of the atmega8, a programming button was included which should be pressed when uploading new firmware. This button connects the programmer to power, and simultaneously pulls the reset pin on the atmega8 to the reset pin on the programmer. This saves power when the programmer is not in use, and ensures the reset pin is never inadvertently pulled down when the programmer is not uploading. The programmer can be left in the board for convenience, or removed after uploading. The schematic for the connections to the progammer and programming button is shown in figure D.4.

A power switch with a translucent orange safety cover was implemented as the shut off switch. It is not clear where this part came from, but it serves the purpose and matches the color of the acrylic sheets used on the robot.

Similar to the motor controller, while the buck converter could have easily been integrated into the PCB, it was decided against due to time constraints. Instead a buck converter module was ordered and tuned to output 5V by turning its onboard potentiometer and verifying with a multimeter.

2) Circuit layout: Thanks to the PCB, the circuit layout is very simple and easy to follow from just the KiCad schematic. The schematic was organized into its various functions, where labels of the same name indicate that a trace on the PCB connects the two elements. The full schematic is shown in figure D.1, and each section is shown individually in appendix D.

3) Algorithm and programming: The IR sensors output very noisy signals, causing the robot to turn frequently even when it wasn't at the edge of the rink. To solve this, a simplistic version of a low pass filter was added in software to ignore signals that are most likely noise. This works because high frequency pulses from the IR sensors are unlikely to be due to the edge of the rink since the robot is not moving very quickly.

The logic for turning around at an IR detection was worked out by using a karnaugh map. In order to avoid being duped by an opponent robot slipping their wedge under the IR sensors of the Rickyshi, the logic was carefully crafted such that the robot will not turn around if IR sensors are triggered from opposite sides of the robot simultaneously. Instead, the robot will detect that it is likely being pushed out and attempt to turn 90 degrees and sweep around to attack the side of the oncoming robot.

While the ultrasonic sensors have not been installed yet, the programming to utilize them is ready and tested. A function to create an arc'd move was written and tested to allow the robot to follow a moving target using the IR sensors. The function takes in two parameters, a number from -255 to 255 that represents the rotation of the robot, and a speed to complete the arc. By adjusting the rotation number in real time according to the data from the ultrasonic sensors, the robot will follow the opponent. In the future, pid control can be added to decrease the oscillation in the algorithm.

In order to create an ard'd move, the function normalizes the speed with the rotation to ensure that the robot will turn as expected when giving both a speed and a rotation which could exceed the max speed of 255 for each motor. For example, if a speed of 255 is given, and a rotation of 255 is given, the robot will not move forward, and simply turn in place at full speed. If however a speed of 200 is given, and a rotation of 200 is given, the robot will turn left quickly and also move forward slightly. Normalizing the 2 inputs provides the correct pwm signal from 0 to 255 to each motor to create this effect. To achieve the proper direction, the function uses the sign of the inputs to send the proper logic to the motor controller. a positive speed and rotation indicates a forward velocity and counter clockwise rotation.

III. Discussion

A. Assembly

Once all the parts are manufactured, and the threaded inserts are heat set into all the various components, assembling the robot is a very straight forward process. The robot is assembled in the following order, for a visual aid, refer to figure C.2.

1) Screw the Motor hubs on to the motor axles
2) Screw the wheels onto the motor hubs
3) Secure the motors to the bottom plate by using the c clamps
4) secure the plastic walls to the top plate
5) secure the top plate onto the c clamps
6) secure the acrylic walls to the plastic walls
7) secure the pcb, and the various electronics to the acrylic top plate
8) insert the battery and wire all electronics into the appropriately labelled screw terminals

B. Performance

Overall, Rickyshi outperformed all of the other robots in the arena, winning almost every match. On the offensive, every head-on collision with the opponent would result in Rickyshi pushing the opponent out of the arena, as the wheels had more traction and the motors had more torque than its opponents. Additionally, the long wedge would get under the opponent and lift the front of the opponent off the ground, as seen in figure III.1, causing their front (and occasionally back) wheels to lift off the arena and lose steering and control.An unforeseen benefit of the steel wedge was steel is reflective in the infrared spectrum, occasionally, the wedge would trigger the opponent's IR sensors causing them to respond as if they had reached the edge of the arena and back themselves out of the arena. Defensively, the body and wedge were also

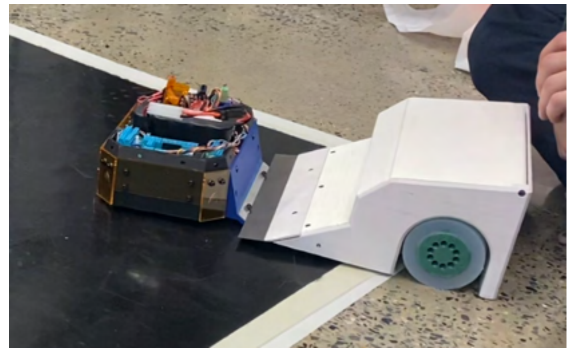

Fig. III.1. Rickyshi pushing opponent out of the arena.

much lower to the ground than any other robot so it was difficult for opponents to get their own wedge under Rickyshi or knock Rickyshi over by pushing on its sides. Opponents were also unable to push Rickyshi very easily, even from the side, because of the very wide, high-traction silicone wheels, the four-wheel drive also meant that if one wheel was lifted, there was still 3 points of contact on the floor and Rickyshi remained controllable. The algorithm worked quite well, keeping Rickyshi within the arena bounds, but when an opponent was pushing Rickyshi over the bounds, it would occasionally turn the wrong way and put itself at a disadvantage. This can be solved in the future with more detection systems, such as ultrasonic sensors, and a more sophisticated response algorithm. The robot had an average current draw of about 2.3A while loaded, giving the robot a life of approximately 1.3hrs of runtime with the 3Ah battery pack onboard.

C. Fixes

Due to an oversight when designing the PCB, the potentiometer was wired to a pin on the Atmega8 which is not capable of analog to digital conversion (ADC). To fix this, an led for debugging was placed into the footprint for the potentiometer and the potentiometer was wired into one of the pins used for the ultrasonic sensors which has ADC capabilities. The problem of sharing a pin for both the potentiometer and ultrasonic sensor was then resolved in software by polling the potentiometer only at the very beginning of the program, and using the pin for the ultrasonic sensors instead until the robot is reset. If the robot is started with the potentiometer all the way to the left, the robot goes into "setup mode" and will continuously update the threshold using the potentiometer for 30 seconds to allow the user to properly tune the IR sensors. After this assigned period of time, the led will blink 3 times, and the program will run as usual.

The IR sensors were initially placed too high above the ground for accurate sensing, rather than re-manufacturing and assembling a frame that accommodates this change we simply broke off the old IR sensor mount and taped the IR sensors lower onto the frame.

IV. Conclusions

Rickyshi is the culmination of a semester's worth of effort and it's beauty is unmatched by all the robots in the land. It defeats its opponents with formidable grace and style. The design was perfected over months of iteration and manufacturing challenges, forging a menace with the quality of a diamond through flame and struggle. The wedge is unmatched in the robot competition space, easily slicing under the front of any robot and causing their wheels to slip with misery. The circuitry works excellently and the control chip is programmed easily with C code, the most pure computer programming language in form and essence proven through the test of time. The robot will run for at least an hour without stopping or even breaking a sweat, and the switch at the top with a safety cover is a representation of the pure power contained with the beast that is Rickyshi. Overall, Rickyshi is a well-designed and meticulously crafted machine, with each component serving a specific purpose to maximize its potential in the arena.

References

[1] Fujisoft. About all japan robot-sumo tournaments, n.d. https://www.fsi.co.jp/sumo/robot/en/about.html, Last accessed on 2023-3-29.

[2] Plaskolite. Safety data sheet: Optix® 1 cell cast acrylic sheet, n.d. https://plaskolite.com/docs/default-source/literature/sds/sds---optix-1-cell-cast-acrylic-sheet.pdf, Last accessed on 2023-5-11.

[3] Polymaker. Safety data sheet according to hazard communication standard (29 cfr 1910.1200): Polylite™ asa, n.d. https://cdn.shopify.com/s/files/1/0548/7299/7945/files/PolyLite_ASA_SDS_US_EN_V1.pdf?v=1640833042, Last accessed on 2023-5-11.

[4] Servocity. 98 rpm econ gear motor, n.d. https://www.servocity.com/98-rpm-econ-gear-motor/, Last accessed on 2023-3-12.

[5] Smooth-On. Safety data sheet sds no. 823a and 823b, n.d. https://www.smooth-on.com/msds/files/BD_DS_Eco_Equ_EZB_EZS_Psy_MS_OOMOO_Reb_ST_SS_Soma_Sol_Sorta.pdf, Last accessed on 2023-5-11.

[6] USA Sumo. Sumo rules and techniques, n.d. https://www.usasumo.com/learn/rules-techniques/, Last accessed on 2023-3-28.

Appendix A
Competition Rules and Requirements

The following are the rules and regulations of the competition as written by the course professor:

A. Spirit of the Problem

- The goal of the competition is for one robot to push the other robot out of the "ring".

B. Competition Rules

- The "ring" will be approximately 3ft by 3ft square, and made from neoprene rubber (McMaster 9455K62 - ASTM D2000 BC).
- The opponents will be placed at one of three starting positions (straight on, 45 degrees, and 90 degrees from opponent) within the ring.
- When signaled, the teams will activate their robots simultaneously.
- The robot will attempt to locate the other robot and push it out of the ring.
- The robot is considered "out of the ring" when more than half of the robot is no longer within the main area of the ring.
- If neither robot has won after 1 minute (or when both teams agree on a draw), the round is considered a draw.
- Bumps and imperfections will be less than 1/8" at any single spot and no more than 1/2" over the entire area.

C. Cost

- The total cost of the robots components may be no more than 200 dollars.
- The cost is calculated as 1/100 the cost to build 100 robots. (NOTE: the cost is NOT what you pay. It is a quoted cost of materials.)
- Materials donated, found, etc must be accounted for at quoted prices for the total cost of the robot.
- Basic electronics package can be assumed to be valued at 25 dollars.

D. Size

- The robot may be no larger than 10"x10"x6"

E. Weight

- The robot may weigh no more than 5 lbs (with all batteries, motors, etc.)

F. Motors

- Motors may not have a stall current of more than 4.5A (each).
- NOTE: Stall current must be documented.

G. Power supply

- The motor power supply must be a combination of AAA, AA or C cells, providing a maximum of 14V (they must be NiCd or NiMH).
- The power supply for electronics may be at the team's discretion, and may feed from the same power supply as the motors.

H. Electronics

- The robot must be controlled by one or more ATMega328P. No other programmable chip is allowed.
- The robot will sense the border of the ring with one or more supplied IR sensors.
- The robot may (though not necessarily) employ additional sensors, a LIDAR sensor will be included in the kits – any additional sensors must be accounted for in the total cost.
- No external control of any sort is allowed.
- The robot MUST have an easy to access kill-switch. This MUST cut ALL current to ALL parts (motors, electronics, logic etc.)

I. Restrictions

- No liquids, gels, compressed gases, or hazardous substances may be employed (except within circuitry, NiCd, or NiMH batteries. No lithium-ion or lead acid batteries)
- No electrical or mechanical weapons are permitted.
- No lasers may be employed. (This includes sensors.)
- The robot may not purposefully damage the other robot (this includes reasonably foreseeable "accidents").
- You may not damage the ring in any way. (this includes, but is not limited to, residue from glue or tape)

J. On Site Documentation

- Manifest of all parts and materials.
- MSDS sheets for all materials.
- RoHS status for all circuity.
- Documented amperage limits of drivers.
- Documented maximum amperage draw for motors.

Appendix B
Parts List

TABLE I. PARTS LIST

Part Name	Vendor	Part Number	Quantity	Price (USD)
1/8” Acrylic Sheet	Canal Plastics	2025	1.5 sqft	6.33
Polylite ASA	Polymaker	PM70991	0.25kg	6.15
Basic Electronics Kit	Professor Cusack	NA	1	25.00
M3 Bolts	McMaster	90380A348	40	3.70
M3 Nuts	McMaster	98689A112	40	1.37
M3 Washers	McMaster	90592A085	40	1.05
98RPM Econ Gear Motor	Servocity	638350	4	59.96
NiMH Battery (12V, 3000mAh)	Servocity	3100-0012-0020	1	44.99
DragonSkin 20 Silicone	Smooth-On	NA	187.6 g	5.91
1” Diameter Aluminum Rod	Online Metals	1090	4 in	2.97
12V to 5V Buck Converter	Amazon	NA	1	7.00
Motor Controller	Amazon	NA	2	5.75
Inertial Motion Sensor	Digikey	LSM6DSOTR	1	3.59

APPENDIX C
CAD DRAWINGS

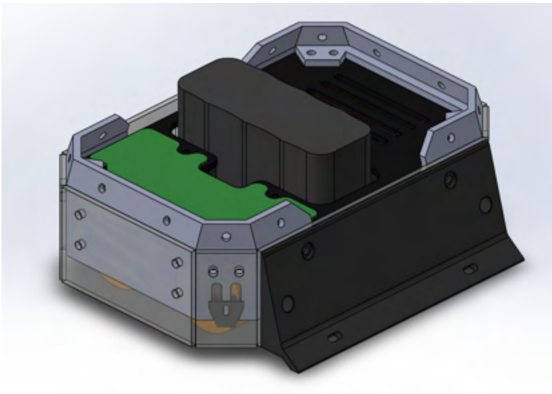

Fig. C.1. Isometric view of CAD

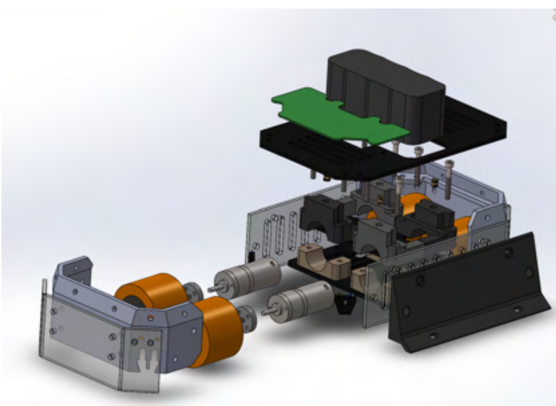

Fig. C.2. Isometric exploded view of CAD

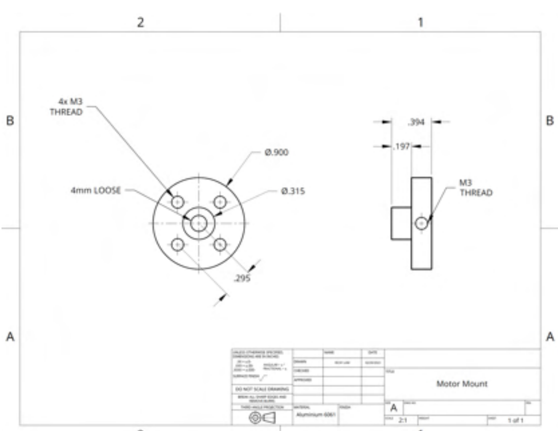

Fig. C.3. Drawing used for machining motor hubs

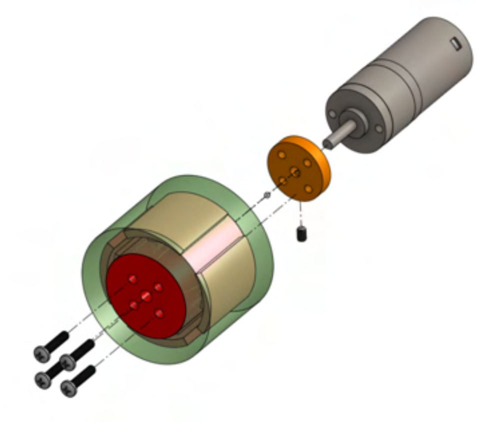

Fig. C.4. Wheel assembly CAD

Appendix D
Circuit Diagrams

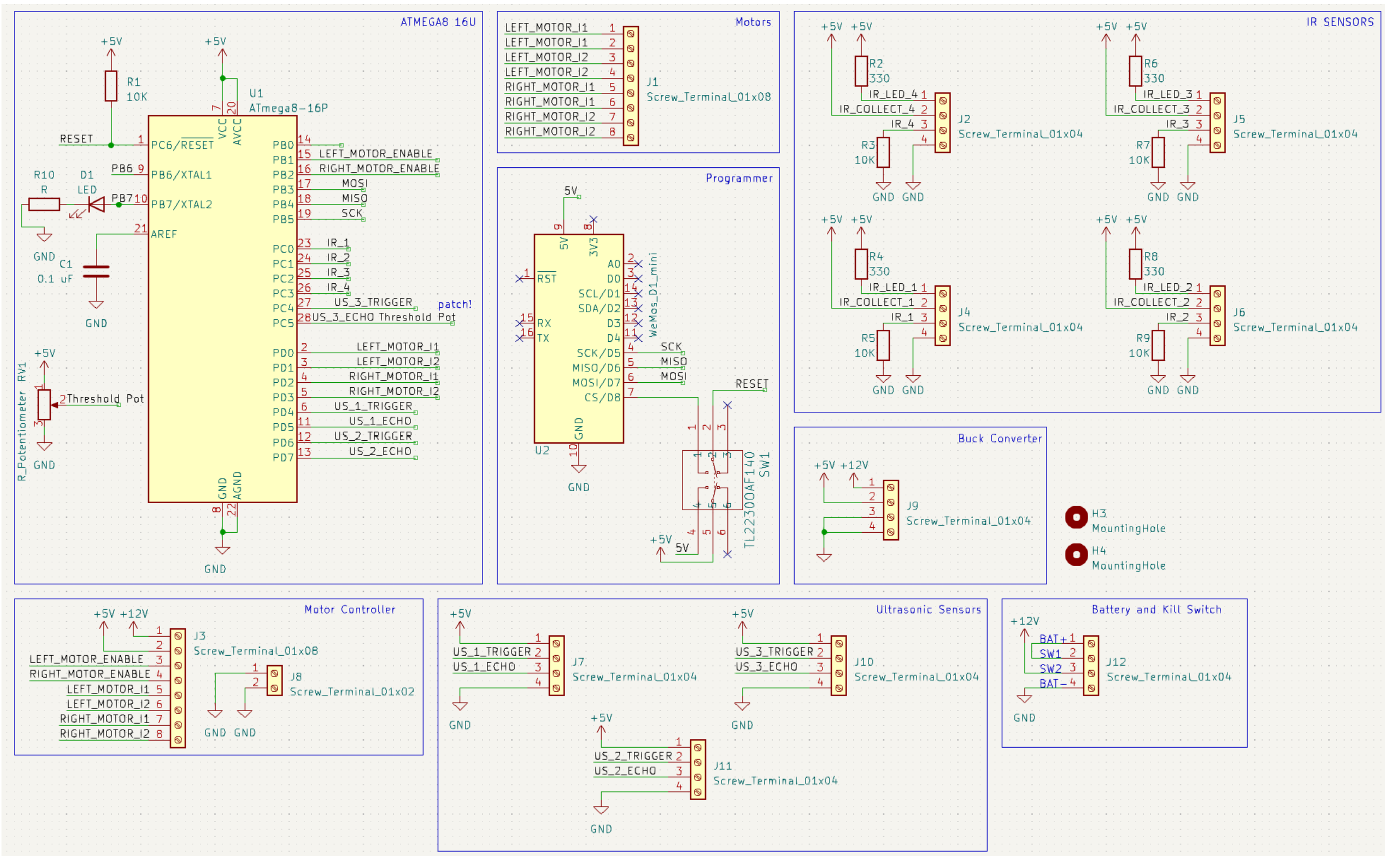

Fig. D.1. KiCad schematic of all connections

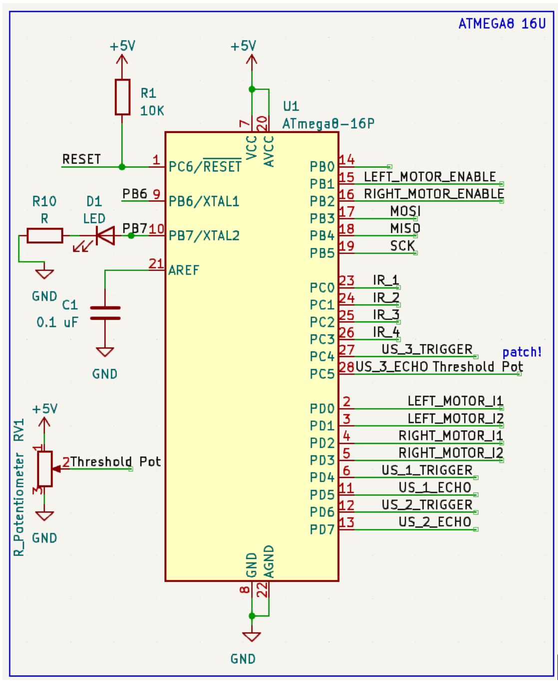

Fig. D.2. KiCad schematic of connections to the ATmega8 16U

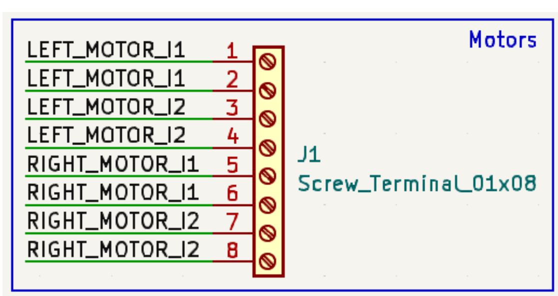

Fig. D.3. KiCad schematic of connections to the Motors

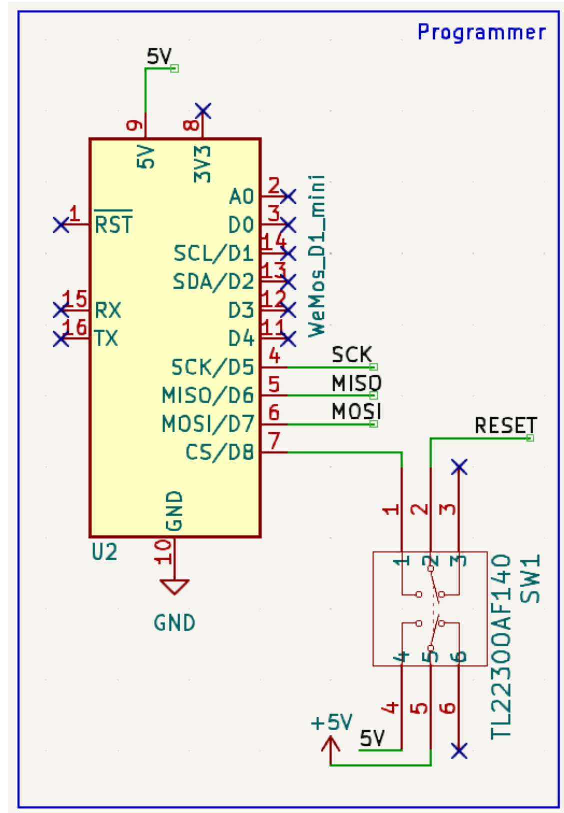

Fig. D.4. KiCad schematic of connections to the Programmer

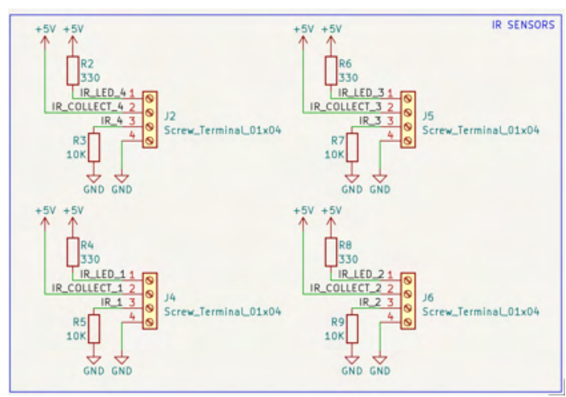

Fig. D.5. KiCad schematic of connections to the IR Sensors

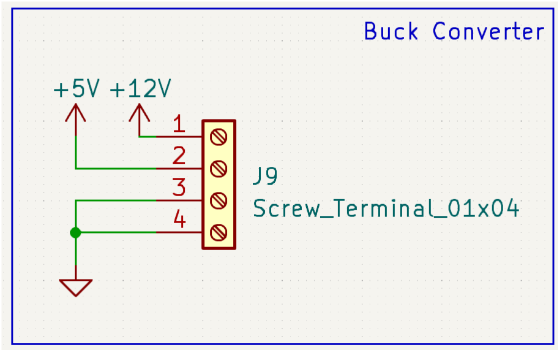

Fig. D.6. KiCad schematic of connections to the Buck Converter

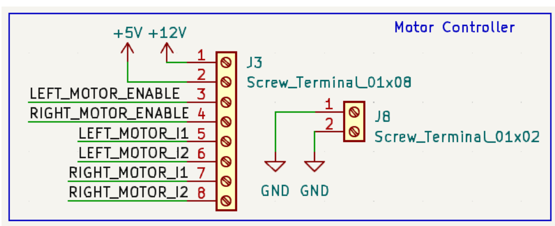

Fig. D.7. KiCad schematic of connections to the Motor Controller

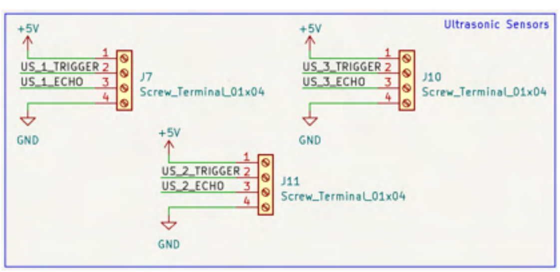

Fig. D.8. KiCad schematic of connections to the Ultrasonic Sensors

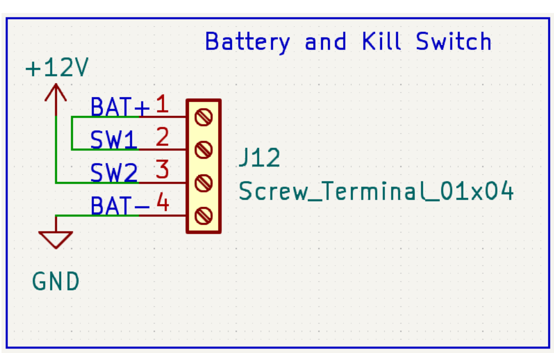

Fig. D.9. KiCad schematic of connections to the Battery and Power Switch

APPENDIX E
CIRCUIT SPECIFICATIONS

Click for links to datasheets.

A. *Matrix 12V 3000mAh NiMH Battery*

No datasheet available.

SPECS

Weight	609g (without adaptor)
Capacity	3,000 mAh
Voltage (Nominal)	12V
Connector	Tamiya Connector [FH-MC]
Cell Size	Sub C
Chemistry	NiMH
Fuse	20A mini blade

Fig. E.1. Specifications for the Battery

B. *Kyuionty DC Motor Driver L298 DC 6.5V-27V 7A Dual H Bridge Motor Speed Controller PWM Motor Regulator Board 12V 24V Motor Control Module Industrial with Optocoupler Isolation, 160W*

C. *LM2596 DC to DC Buck Converter 3.0-40V to 1.5-35V Power Supply Step Down Module*

D. *AtMega8 16U*

E. *Toggle Switch and Cover - Illuminated (Red)*

- Rated for 12V 20A
- Includes Missile Switch Cover
- Illuminated

Fig. E.2. Mission Switch Specs

F. *https://www.servocity.com/98-rpm-econ-gear-motor/*

No datasheet available.

SPECS

Output Shaft Style	D-shaft
Motor Type	Brushed DC
Output Shaft Support	Bushing
Gear Material	Metal
Weight	3.21 oz (91g)
Voltage (Nominal)	12V
Speed (No Load @ 12VDC)	98 rpm
Current (No Load @ 12VDC)	0.10A
Current (Stall @ 12VDC)	3.8A
Torque (Stall @ 12VDC)	524 oz-in (37.76 kgf-cm)
Gearbox Style	Straight Cut Spur
Connector Type	Male Spade Terminal
Gear Ratio	100:1

Fig. E.3. motor specifications.

Appendix F
MSDS

A. Cast Acrylic Sheet

[2] **Relevant Information from the SDS:**
This material is classified as not hazardous under OSHA regulations. Low toxicity under normal conditions of handling and use. Combustion or thermal decomposition will evolve toxic, irritant and flammable vapors. Care should be taken during thermoforming to ensure that the product is not exposed to temperatures exceeding 392°F (200°C). Certain machining operations (e.g. laser cutting) can give rise to toxic and corrosive fumes. Adequate ventilation MUST be used.

COMPOSITION:
Methyl Methacrylate [CAS 9011-14-7]

FIRST AID MEASURES:
Inhalation: Dust or fumes from fabrication operations may cause irritation.
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
Skin Contact: Unlikely to cause skin irritation.
IF ON SKIN: Wash with plenty of soap and water. If skin irritation or rash occurs: Get medical attention.
Eye Contact: Dust or fumes from fabrication operations may cause irritation.
IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Ingestion: Low oral toxicity. Do not induce vomiting. Rinse mouth.

FIRE-FIGHTING MEASURES
Suitable Extinguishing Media: Water spray, foam, dry powder or CO2.
Specific Fire Hazards: Combustion will evolve toxic, irritant and flammable vapors.
Special Protective Equipment and Precaution for Fire Fighters: A self-contained breathing apparatus and suitable protective clothing should be worn in fire conditions.

ECOLOGICAL INFORMATION
Ecotoxicity: This product should have low toxicity to aquatic and terrestrial organisms.
Mobility: Due to the solid nature of this product, it should have low mobility in soil.
Persistence and Degradability: This product is non-biodegradable.
Bioaccumulation: This solid product has a low potential for bioaccumulation.

B. ASA 3D Printing Filament

[3]

COMPOSITION:
Acrylonitrile Styrene Acrylate (ASA) [CAS 25852-38-4]

FIRST AID MEASURES:
Eye contact: None expected to require first aid measures. Flush with running water for at least 15 minutes. If irritation persists get medical attention.
Skin contact: None expected to require first aid measures. Wash thoroughly with soap and water. Get medical attention in the unlikely event that irritation persists.
Inhalation: None expected to require first aid measures. If breathed in, remove victim to fresh air and keep at rest in a position comfortable for breathing. If you feel unwell, seek medical attention.
Ingestion: Immediate first aid is not likely to be required. A physician or poison control center can be contacted for advice.

FIRE-FIGHTING MEASURES
Flammable properties: Not available.
Extinguishing media: Use extinguishers suitable for surrounding fire.
Firefighting equipment/instructions: Wear self contained breathing apparatus for fire fighting if necessary.
Hazardous combustion products: Carbon oxides.

EXPOSURE CONTROLS/PERSONAL PROTECTION
Occupational exposure limits: This substance has no PEL, TLV, or other recommended exposure limit.
Biological limit values: No biological exposure limits noted for the ingredient(s).
Appropriate engineering controls: Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

C. Dragon Skin 20 Silicone

[5]

HAZARDS IDENTIFICATION

Classification of the substance or mixture: Not a hazardous substance or mixture according to United States Occupational Safety and Health Administration (OSHA).

FIRST AID MEASURES:

Inhalation: Remove source(s) of contamination and move victim to fresh air. If breathing has stopped, give artificial respiration, then oxygen if needed. Contact physician immediately.

Eye Contact: Flush eyes with plenty of water. If irritation persists, seek medical attention.

Skin Contact: In case of skin contact, wash thoroughly with soap and water.

Ingestion: Do not induce vomiting unless instructed by a physician. Never give anything by mouth to an unconscious person.

FIRE-FIGHTING MEASURES

Extinguishing Media: Water Fog, Dry Chemical, and Carbon Dioxide Foam

Special hazards arising from the substance or mixture: None known.

Advice for firefighters: Use water spray to cool fire-exposed surfaces and to protect personnel. Shut off "fuel" to fire. If a leak or spill has not ignited, use water spray to disperse the vapors. Either allow fire to burn under controlled conditions or extinguish with foam or dry chemical. Try to cover liquid spills with foam. Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full-face piece operated in pressure demand or positive-pressure mode.

ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures: Only properly protected personnel should remain in the spill area; dike and contain spill. Stop or reduce discharge if it can be done safely.

Environmental precautions: Stop spill/release if it can be done safely. Prevent spilled material from entering sewers, storm drains or unauthorized drainage systems and natural waterways by using sand, earth, or other appropriate barriers. No special environmental precautions required.

Methods and material for containment and cleaning up: Put on appropriate protective gear including NIOSH/MSHA approved self-contained breathing apparatus, rubber boots and heavy rubber gloves. Dike and contain spill; Absorb or scrape up excess into suitable container for disposal; wash area with dilute ammonia solution.